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A compact gas-filled avalanche counter for DANCE

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Abstract

A compact gas-filled avalanche counter for the detection of fission fragments was developed for a highly segmented 4π γ -ray calorimeter, namely the Detector for Advanced Neutron Capture Experiments located at the Lujan Center of the Los Alamos Neutron Science Center. It has been used successfully for experiments with ^{235}U , ^{238}Pu , ^{239}Pu , and ^{241}Pu isotopes to provide a unique signature to differentiate the fission from the competing neutron-capture reaction channel. It also was used to study the spontaneous fission in ^{252}Cf . The design and performance of this avalanche counter for targets with extreme α -decay rate up to $\sim 2.4 \times 10^8$ /s is described.

Keyword:

Fission, Uranium, Plutonium, Californium-252, Gas-filled avalanche counter

I. Introduction

The Detector for Advanced Neutron Capture Experiments (DANCE) [1] is a 4π γ -ray calorimeter and located at the Lujan Center of the Los Alamos Neutron Science Center (LANSC), where the neutron beam with the energy from thermal up to about 100 keV is produced. DANCE consists of 160 BaF₂ crystals and each crystal has equal solid-angle coverage. DANCE was designed to study the neutron-capture reactions on small quantities of radioactive and rare stable nuclei. These reactions are important for the radiochemistry applications and modeling the element production in stars. Neutron-capture events are recognized by the measured total γ -ray energy and the summed photopeak energy is equivalent of the reaction Q -value plus the kinematic energy of the incident neutron. For a selective group of actinides where the neutron-induced fission competes favorably with the neutron capture reaction, an additional signature is needed to establish the origin of γ rays. This can be accomplished by introducing a fission counter to detect the fission fragments and thus establish a unique signature for fission γ rays. Once this system is implemented, one has opportunity to study not only the neutron capture reaction but also the fission with the DANCE array [2].

A parallel-plate avalanche counter (PPAC) has many advantages for the detection of heavy charged particles such as fission fragments. These include the fast timing, the resistance to radiation damage, and the tolerance of high counting rate. A PPAC also can be tuned to be insensitive to α particles, which is important for experiments with α -emitting actinides. Therefore, a PPAC is an ideal detector for experiments requiring a fast and clean trigger for fission. A PPAC with an ingenious design was fabricated for DANCE in 2006 [3] by integrating amplifiers into the target assembly. However, this counter was proved to be unsuitable for this application because of issues related to the stability of the counter performance and the ability to separate fission fragments from α 's. Therefore, a fission counter with different design is needed.

A new PPAC for DANCE was designed and fabricated in 2009 – 2010. The goal of this redesign is to seek the long-term stability of the counter operation under extreme α -radioactivity. This can be accomplished by developing a low-noise, high-gain and high-bandwidth amplifier, detached from the counter itself. A minimum mass for the construction material also is a major consideration in this redesign to minimize the γ -ray absorption but still keep the mechanical strength. In the following sections, the descriptions are given for the design and performance of this new compact PPAC, which is used together with DANCE at LANSC to study the neutron-induced reactions on actinides.

II. Design of a new parallel-plate avalanche counter for DANCE

The design work is a no-trivial task because of the limited space to accommodate the counter assembly and was carried out initially by Mechtronic Solutions, Inc. [4]. Later, an extensive redesign work was made at Lawrence Livermore National Laboratory (LLNL) mainly to correct issues related to the vacuum seal as well as the electric and gas feedthroughs. The fabrication work was carried out entirely at LLNL.

The newly designed PPAC has three mechanical parts, shown in Fig 1. They are the front cover with the attached counter/target assembly, the aluminum container with a wall thickness of 0.76 mm to host the assembly, and the back cover with both the electric and gas feedthroughs. Shown also in Fig. 1 are the exploded views of anodes and cathode, which are housed by the polyimide rings, then stacked into the counter/target assembly. The cathode holds a 3 μm thick Ti foil with the target material that is sandwiched between two 1.4 μm thick aluminized mylar. The target material is electrodeposited double-sided using the plating cell described in Ref. [5]. The mylar is glued to the copper ring with a thickness of 0.25 mm. A delrin retaining ring of 0.66 mm thickness is used to confine the assembly in the polyimide ring. The anodes are made of the same thickness mylar using the same mechanism to keep the assembly fixed in the polyimide ring. The distance between the anode and cathode is 3 mm. The cathode is grounded and the anode signal is transmitted through a custom-made flexible cable, which can be seen protruding from the back cover in Fig. 1. The front and back windows for the beam entrance and exit are made of 25.4 μm thickness Kapton foils, which were glued to the covers.

The principle of a minimum mass for the current PPAC construction is applied and the degradation of the γ -ray efficiency amounts $\sim 4\%$ and $\sim 1\%$ for the γ -ray energy at 200 keV and 1 MeV, respectively [6].

III. Operation and performance

For a stable operation of the PPAC, it requires continuous gas flow into the counter while maintaining a constant gas pressure. This can be achieved by using a specialized gas handling system to regulate the gas flow via a feedback loop on the measurement of gas pressure. The description of a similar gas handling system and its operation is detailed in ref. [7,8].

The PPAC is operated at ~ 4 torr of isobutane with a gas flow $\sim 5 - 7$ sccm. The signal from the anode, biased at $\sim +400$ V, is processed by a LLNL developed fast amplifier with a gain about 300 and a bandwidth of 500 MHz, located outside the DANCE array. The output of amplifier, which has a rise time $\sim 3 - 4$ ns and several hundred mV on average for fission fragments, is directly fed into the Acqiris digitizers, same to those used for DANCE. The timing and pulse height of the anode signal are derived from the recorded waveform. The time spectrum between the γ rays detected by DANCE and the fission fragments detected by PPAC for the ^{235}U target with a total mass about 923 μg is shown in Fig. 2, where the time resolution ~ 1.7 ns is achieved.

For actinide targets, it is important to keep the impact of the intrinsic radioactivity on PPAC to a minimum. As mentioned earlier, a PPAC can be tuned to be insensitive to α 's. However, for the current setup one can only minimize the sensitivity to α 's but can't totally eliminate it due to the nature of internal target, where the decay particles can have very different flight path. An example is given in Fig. 3, where the pulse height spectrum is shown for the ^{241}Pu target with a total mass of about 147 μg . The target radioactivity is about 5.4×10^8 β/s and 3.3×10^4 α/s . The latter includes the decay from the ^{239}Pu

contamination in the target. The separation of fission fragments from α 's is reasonable once a coincident time window ~ 8 ns is imposed on the time spectrum, similar to that shown in Fig. 2 and the amplitude of α peak drops nearly an order of magnitude relative to that of fission fragments. By selecting the fission fragments in the pulse height spectrum, shown in Fig. 3, one can derive the prompt γ -ray energy and multiplicity distributions in fission from DANCE. An example of the derived data is demonstrated in Fig. 4, where the total γ -ray energy vs. multiplicity spectrum in fission is plotted for the ^{235}U target.

In addition to the ^{235}U and ^{241}Pu targets, we also have fielded experiments for the ^{239}Pu target with a total mass ~ 937 μg and a radioactivity $\sim 2.2 \times 10^6$ α/s as well as a ^{252}Cf source with a strength ~ 0.15 μCi using DANCE together with the newly designed PPAC. The PPAC ran very stable during the experiments, which typically last about two to three weeks for the actinide targets and achieved the detection efficiency for fission fragments $\sim 70\%$ on average. Since all the experiments were performed in the inclusive mode, one can estimate the PPAC detection efficiency by comparing the events with the total γ -ray (energy, multiplicity) $\geq (10$ MeV, 8), to those with an additional requirement on the detection of fission fragments. All the neutron-capture events are excluded by this specific requirement on the total γ -ray energy vs. multiplicity distribution.

In addition to the use for the neutron-induced reactions on actinides, this PPAC also can be employed to explore the fission from a source, such as ^{252}Cf . Together with DANCE; the prompt γ rays in the spontaneous fission can be measured and studied. By investigating the correlation between the γ -ray energy and multiplicity distributions, the stochastic aspect of the γ -ray emission in fission is identified [6].

Two PPAC's were fabricated for the ^{238}Pu target. One with a total mass ~ 40 μg and a radioactivity $\sim 2.5 \times 10^7$ α/s , performed reasonably well during the experiment but the efficiency lowered to $\sim 20 - 25\%$ maximum due to the gas gain was deduced by a factor of 3 – 4 than those of earlier measurements with less radioactive targets at the same bias. This deterioration can be attributed to a nearly constant discharge from the α decay, resulting in a reduced effective bias on the counter. However, the time resolution ~ 2 ns is achieved and the peak-to-background ratio is better than 10 to 1 for the time spectrum between the PPAC and DANCE, which is shown in Fig. 5. The efficiency deteriorated quickly down to a few percents for the detection of fission fragments for the PPAC with a total mass ~ 374 μg and a radioactivity $\sim 2.4 \times 10^8$ α/s . Under this circumstance, the usefulness is limited for a PPAC to provide the signature to differentiate the fission from the neutron-capture channel.

IV. Summary

A new gas-filled parallel-plate avalanche counter for DANCE was developed at LLNL. Both the design and fabrication are described. It performed well and stably during experiments and has been used very successfully to study both fission and the neutron capture channel for a number of highly radioactive actinides. The efficiency for the detection of fission fragment has reached $\sim 70\%$ on average with the radioactivity below

2.5 $\times 10^7$ α /s. Thus an upper bound is established for the radioactivity tolerance of PPAC with an internal target of a 7 mm diameter in size over an active area about 700 mm².

[1] M. Heil, R. Reifarh, M.M. Fowler, R.C. Haight, F. Kappeler, R.S. Rundberg, E.H. Seabury, J.L. Ullmann, J.B. Wilhelmy, and K. Wisshak, Nucl. Instrum. Methods Phys. Res. A 456 (2001) 229.

[2] T.A. Bredeweg, M.M. Fowler, J.A. Becker, E.M. Bond, M.B. Chadwick, R.R.C. Clement, E.I. Esch, T. Ethvignot, T. Granier, L.F. Hunt, R.A. Macri, J.M. O'Donnell, R.S. Rundberg, J.M. Schwantes, J.L. Ullmann, D.J. Vieira, J.B. Wilhelmy, J.M. Wouters, C.Y. Wu, and J.E. Yurkon, Proceedings of 12th International Symposium on Capture Gamma-Ray Spectroscopy and Related Topics, edited by A. Woehr and A. Aprahamian (American Institute of Physics, New York, 2006), p. 568.

[3] T.A. Bredeweg, M.M. Fowler, J.A. Becker, E.M. Bond, M.B. Chadwick, R.R.C. Clement, E.-I. Esch, T. Ethvignot, T. Granier, M. Jandel, R.A. Macri, J.M. O'Donnell, R. Reifarh, R.S. Rundberg, J.L. Ullmann, D.J. Vieira, J.B. Wilhelmy, J.M. Wouters, and C.Y. Wu, Nucl. Instrum. Methods Phys. Res. B 261 (2007) 986.

[4] Mechtronic Solutions, Inc., Albuquerque, NM 87109.

[5] R.A. Henderson, J.M. Gostic, J.T. Burke, S.E. Fisher, and C.Y. Wu, Nucl. Instrum. Methods Phys. Res. A 655 (2011) 66.

[6] A. Chyzh, C.Y. Wu, E. Kwan, R.A. Henderson, J.M. Gostic, T.A. Bredeweg, R.C. Haight, A.C. Hayes-Sterbenz, M. Jandel, J.M. O'Donnell, and J.L. Ullmann, Phys. Rev. C 85, 021601(R) (2012).

[7] M.W. Simon, D. Cline, C.Y. Wu, R.W. Gray, R. Teng, and C. Long, Nucl. Instrum. Methods Phys. Res. A 452 (2000), 205.

[8] C.Y. Wu, R. Henderson, J.M. Gostic, R.C. Haight, and H.Y. Lee, Lawrence Livermore National Laboratory, LLNL-TR-461044 (2010).

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Figure caption

Fig. 1 The exploded view of the newly designed PPAC for the DANCE array for the detection of fission fragments. The PPAC consists of two anodes, which electrically connected, and the cathode. The anode, shown in the upper right corner, is made of the double-side aluminized mylar with a thickness of $1.4\ \mu\text{m}$ and glued to the copper ring. The delrin retaining ring, shown in white, is used to confine the assembling in the polyimide ring. The cathode, shown in the lower center, includes the Ti foil with the target material deposited in an area of 7 mm diameter, then sandwiched between two aluminized mylar foils. This anode/cathode assembling is fastened to the front cover using rods and screws. Both the electrical and gas feedthroughs can be seen protruding from the back cover.

Fig. 2 The time spectrum between the detection of fission fragments by PPAC and the detection of γ rays by DANCE for the ^{235}U target. The time resolution $\sim 1.7\ \text{ns}$ is achieved. The broad bump next to the narrow peak is resulted from events with an ambiguous time correlation between PPAC and DANCE.

Fig. 3 The pulse height spectrum for the detected fission fragments by PPAC for the ^{241}Pu target, shown as dashed line. The broad peak is originated from the detected fission fragments and the narrow peak to the left is arisen from α 's. The α 's are significantly reduced in the spectrum with a gate on the coincident time spectrum, shown as solid line.

Fig. 4 The measured total γ -ray energy vs. multiplicity distribution for the neutron-induced fission in ^{235}U .

Fig. 5 The same as Fig. 2 except for the ^{238}Pu target with a total mass $\sim 40\ \mu\text{g}$. The time resolution $\sim 2\ \text{ns}$ is achieved, indicating the PPAC still functioned well with the α rate at $\sim 2.5 \times 10^7\ /\text{s}$.

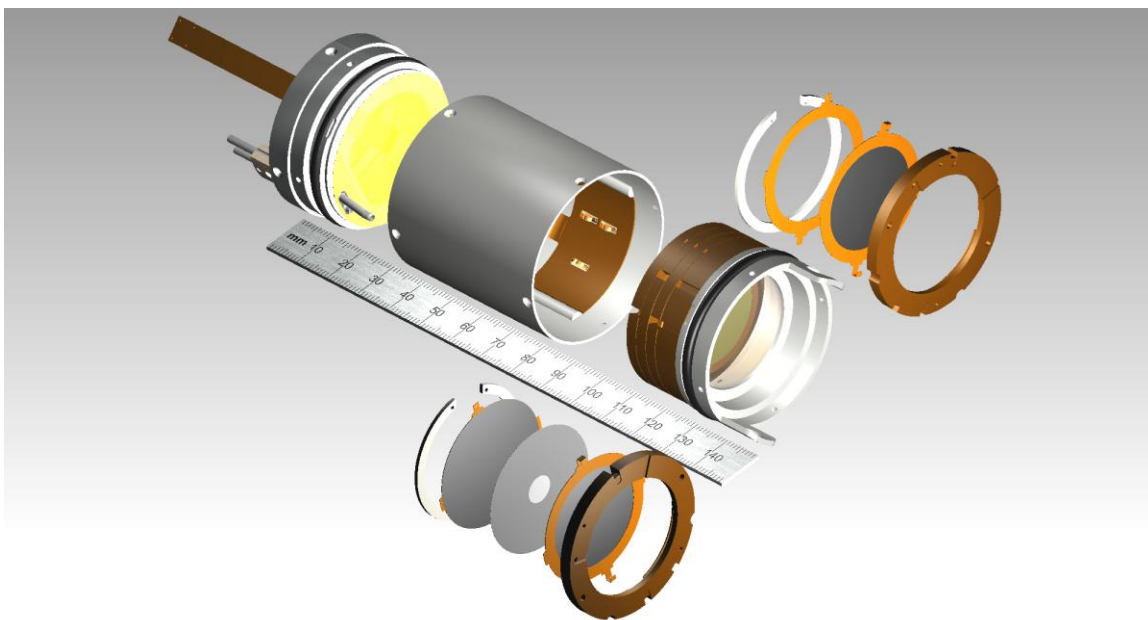


Fig. 1

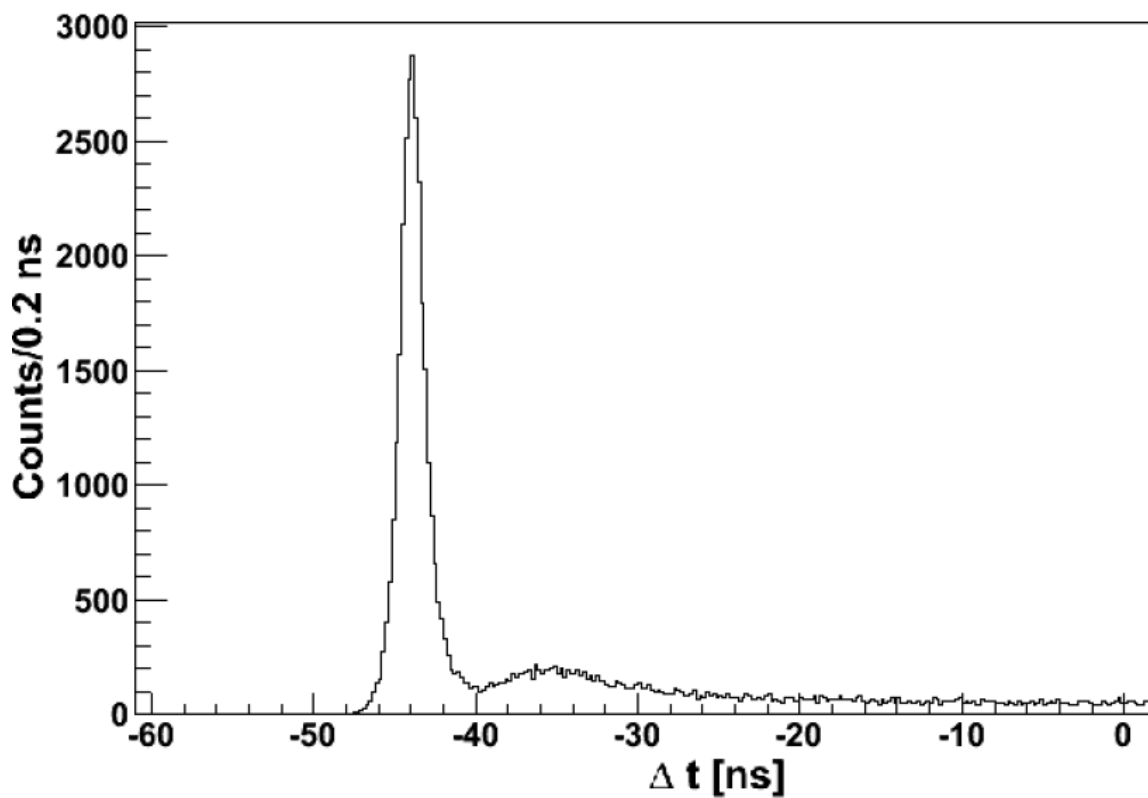


Fig. 2

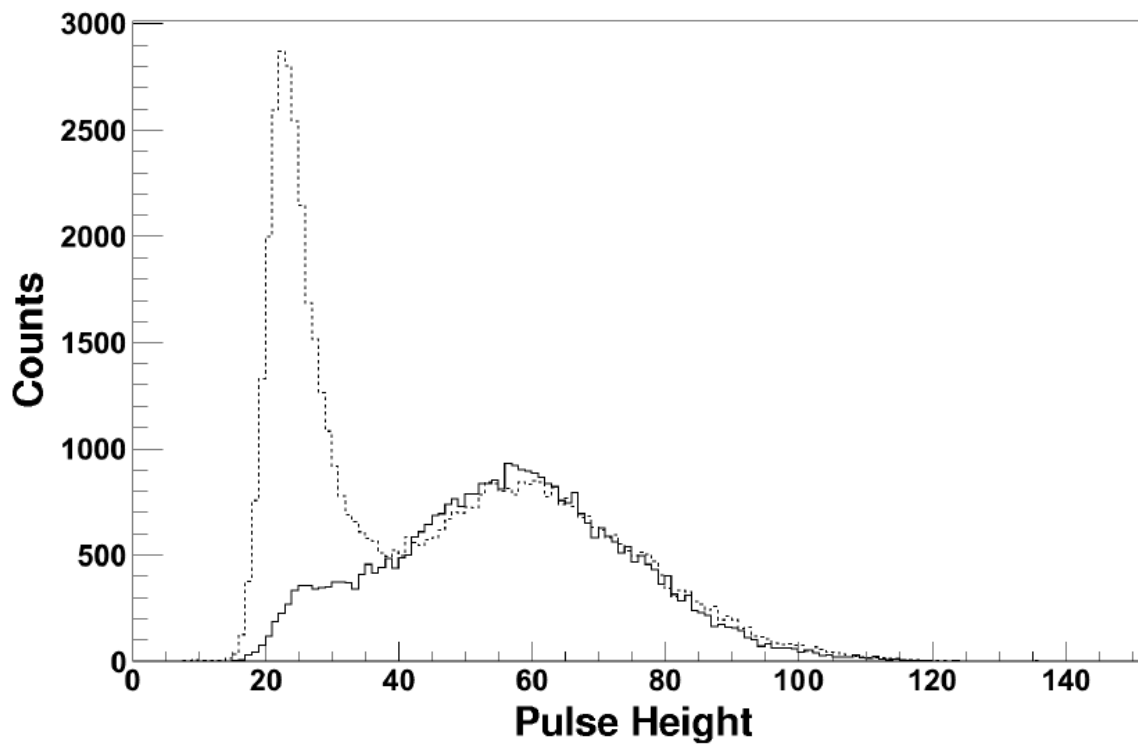


Fig. 3

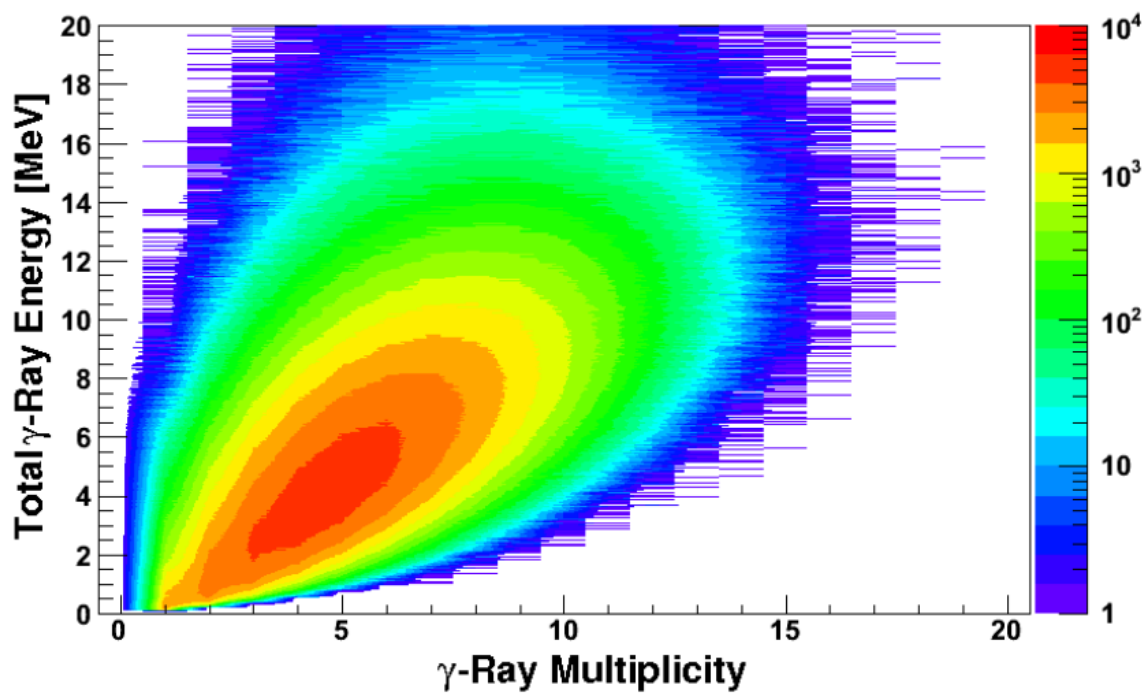


Fig. 4

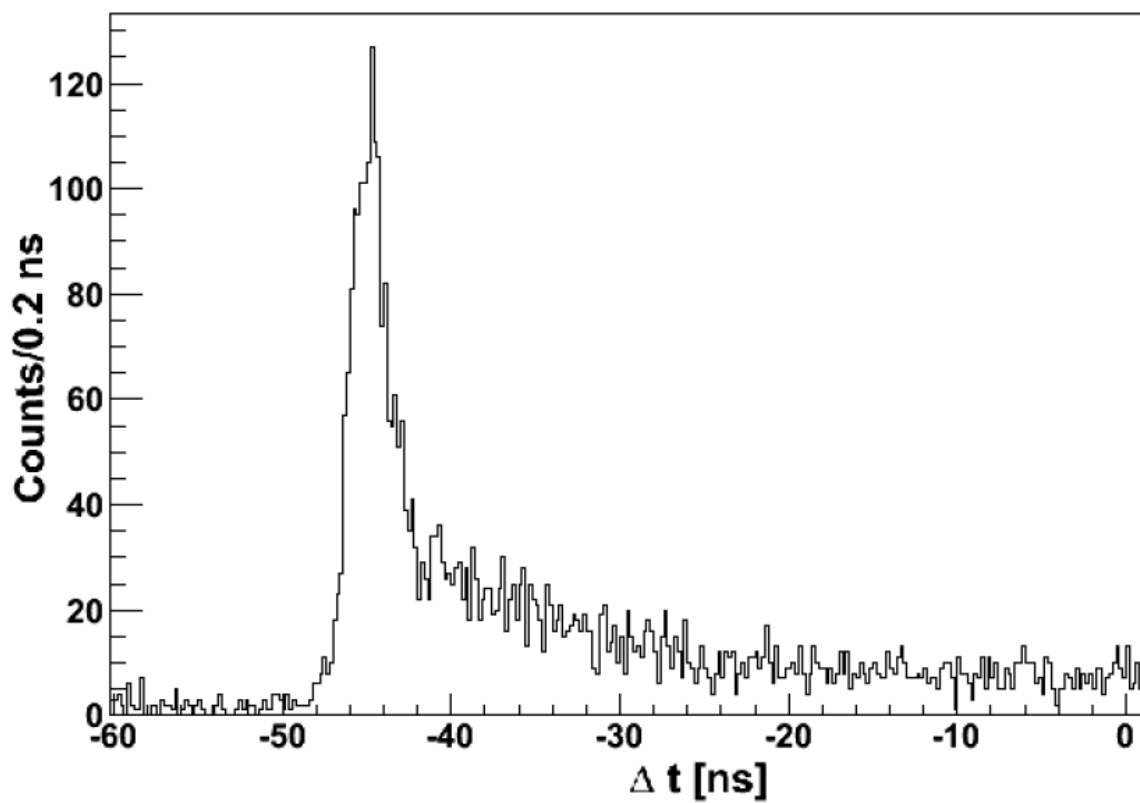


Fig. 5